

# Status and Plans for Advanced Design Activities

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Electronic copy: <http://aries.ucsd.edu/najmabadi/TALKS/>

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# Status of Advanced Design Activities

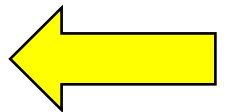
Breakdown of the Advanced Design Activities:

- Socioeconomics: Studies of markets, customers, and the role of fusion in a sustainable global energy strategy

<b>Budgets:</b>	<u>FY03</u>	<u>FY04</u>	<u>FY05 (CBR)</u>
	\$217k	\$30k	\$150k

- “System Studies”: ARIES National Fusion Power Plant Studies Program

<b>Budgets:</b>	<u>FY03</u>	<u>FY04</u>	<u>FY05 (CBR)</u>
	\$2.1 M	\$1.6 M	\$1.6 M



# ARIES Research Bridges the Science and Energy Missions of the US Fusion Program

## ➤ Mission Statement:

**Perform advanced integrated design studies of the long-term fusion energy embodiments to identify key R&D directions and provide visions for the program.**

- Commercial fusion energy is the most demanding of the program goals, and it provides the toughest standard to judge the usefulness of program elements.
- Knowledge base of fusion power plants involves subtle combinations of physics, technology, and engineering. Extensive systems studies are needed to identify not just the most effective experiments for the moment, but also the most cost-effective routes to the evolution of the experimental, scientific and technological program.

**Selected Results from ARIES  
Research in FY03/FY04**

# ARIES Program charter was expanded in FY00 to include both IFE and MFE concepts

## ARIES activities in FY03:

- **ARIES-IFE study was continued for another year (~50% of the effort):**
    - ✓ The ARIES-IFE study is now officially completed.
    - ✓ Work in FY03 was focused on thick-liquid wall concept (*i.e.*, HYLIFE)
    - ✓ Results from 2001 and 2002 research will appear in Journal of Fusion Science & Technology (pre-prints available on ARIES Web site).
  - **ARIES compact stellarator (ARIES-CS) was started (~50% of the effort)**
    - ✓ This is a ~~three~~ four-year study (because of budget reductions.)
- FY04 ARIES activity is entirely on compact stellarators.

# ARIES Integrated IFE Chamber Analysis and Assessment Research Is An Exploration Study

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## Objectives:

- Analyze & assess integrated and self-consistent IFE chamber concepts
- Understand trade-offs and identify design windows for promising concepts. *The research is **not** aimed at developing a point design.*

## Approach:

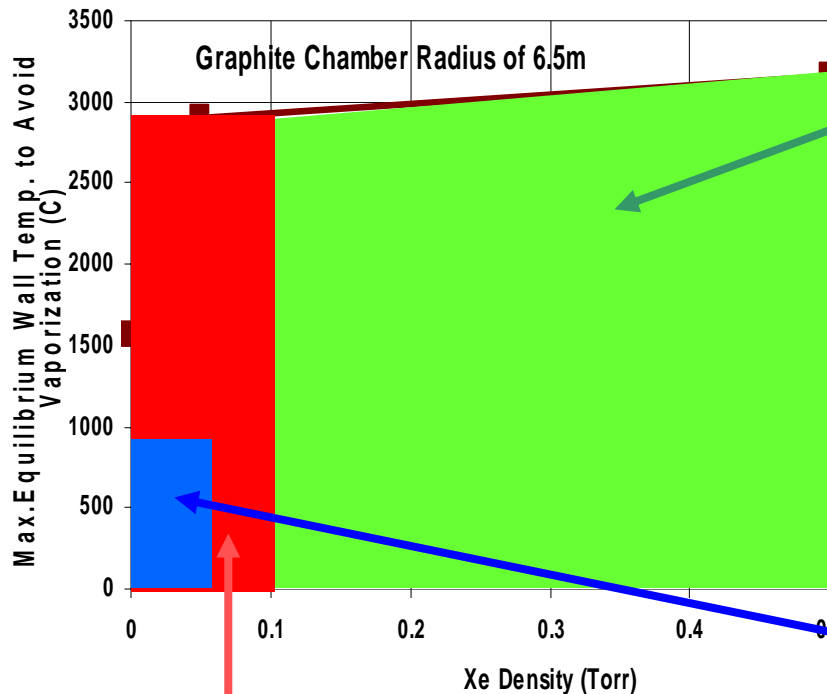
- Six classes of target were identified. Advanced target designs from NRL (laser-driven direct drive) and LLNL (Heavy-ion-driven indirect-drive) are used as references.
- We have found that the chamber response critically depends on the spectrum of target emissions as well as the target yield.
- To make progress, we divided the activity based on three classes of chambers:
  - Dry wall chambers;
  - Solid wall chambers protected with a “sacrificial zone” (such as liquid films);
  - Thick liquid walls.

# Some Highlights from Dry Wall Study

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- Parametric design window developed showing possibility of chamber operation with reasonable chamber, driver and target parameters
  - ✓ Detailed transient analysis of armor shows importance of time-of-flight effects on armor lifetime.
  - ✓ Target survival constraints on chamber gas conditions (governing the energy exchange to the target during injection) are very restrictive.
  - ✓ Operating design window exists but would substantially benefit from more thermally robust target (*e.g.*, with an insulating foam layer).
  - ✓ IFE armor conditions are within ~1 order of magnitude of some MFE transient cases (*e.g.*, ELM's) showing the potential synergy between MFE & IFE armor R&D
  - ✓ The results from ARIES-IFE dry wall chamber effort has had a major impact in guiding the on-going HAPL study

# Design Windows for Direct-Drive Dry-wall Chambers



## Thermal design window

- ✓ Detailed target emissions
- ✓ Transport in the chamber including time-of-flight spreading
- ✓ Transient thermal analysis of chamber wall
- ✓ No gas is necessary

## Target injection design window

- ✓ Heating of target by radiation and friction
- ✓ Constraints:
  - Limited rise in temperature
  - Acceptable stresses in DT ice

## Laser propagation design window(?)

- ✓ Experiments on NIKE

# Aerosol Generation and Transport is the Key Issue for Thin-Liquid Wall Concepts

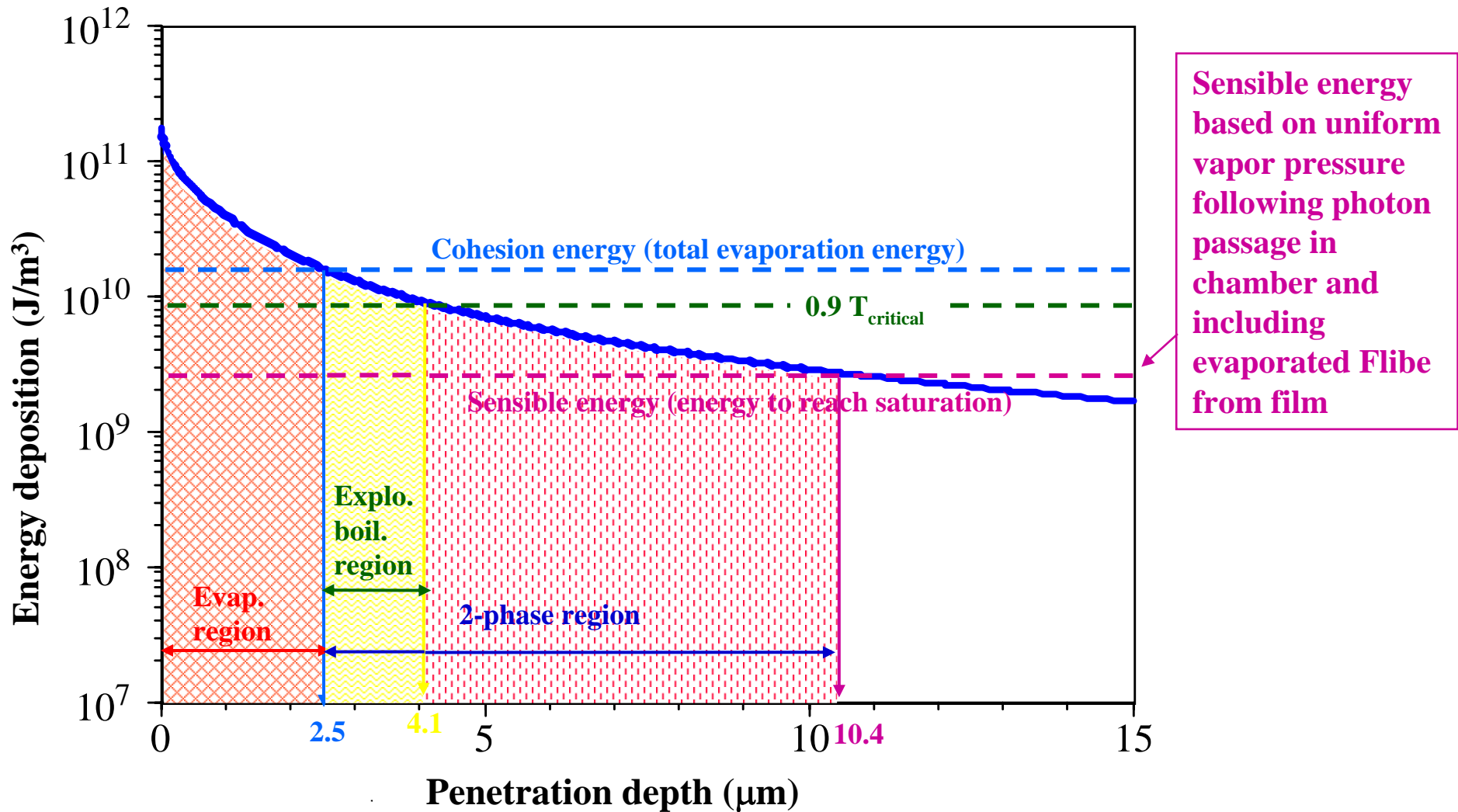
A renewable thin-liquid protection resolve several issues:

- It can handle a much higher heat fluxes compared to solid surfaces;
- It will eliminate damage to the armor/first wall due to high-energy ions.

A renewable thin-liquid protection, however, introduces its own critical issues:

- Fluid-dynamics aspects (establishment and maintenance of the film)
  - ✓ “Wetted wall:” Low-speed normal injection through a porous surface
  - ✓ “Forced film:” High-speed tangential injection along a solid surface
- Chamber clearing (recondensation of evaporated liquid)
  - ✓ “Source term:” both vapor and liquid (e.g., explosive boiling) are ejected
  - ✓ Super-saturated state of the chamber leads to aerosol generation
  - ✓ Target injection and laser beam propagation lead to sever constraints on the acceptable amount and size of aerosol in the chamber.

# Photon Energy Deposition Density Profile in Flibe Film and Explosive Boiling Region (6.5m chamber)



# Some Highlights from Thick-Liquid Wall Study

➤ We focused on HYLIFE-like conditions

- We performed an assessment of structural material for HYLIFE
- ✓ 304 SS previously considered to minimize development cost
  - ✓ However, 304 SS has major swelling, activation and He embrittlement issues, in particular thermal creep limits which would reduce the maximum temperature to about 550°C and thus substantially close the flibe operating temperature window for power plant application.
  - ✓ We strongly recommended that alternate structural material candidates offering the possibility of higher operating temperature and performance be considered (e.g. ODS FS)
  - ✓ Complete report at: <http://aries.ucsd.edu/LIB/REPORT/ENG.shtml>

# Some Highlights from Thick-Liquid Wall Study

- Aerosol source term and behavior analysis extended to thick liquid wall
  - ✓ Aerosol generation and transport is also critical issue for thick-liquid wall concepts.
  - ✓ Several mechanism for material loss and aerosol formation such as spalling of thick jets were identified.
- Modeling and experimental studies of jet flow
  - ✓ Hydrodynamic source term sensitive to initial conditions
  - ✓ Flow conditioning / converging nozzle reduces droplet mass flux (and number density) by 3–5 orders of magnitude over model predictions
  - ✓ Boundary layer cutting appears to eliminate droplet ejection for a “well-conditioned” jet
  - ✓ Preventing blockage of fine mesh screens major issue

**ARIES Research Plans  
for FY03-FY06**

# Exploration and Optimization of Compact Stellarators as Power Plants -- Motivations

## **Timeliness:**

- Initiation of NCSX and QSX experiments in US; PE experiments in Japan (LHD) and Germany (W7X under construction).
- Review committees have asked for assessment of compact stellarator option as a power plant; Similar interest has been expressed by national stellarator program.
- FESAC recommended that timely power-plant studies be performed for Proof-of-Principle and PE programs in order to guide experimental programs.
- Progress in our theoretical understanding, new experimental results, and the design effort for the above experiments has led to the development of a host of sophisticated physics tools.

# Exploration and Optimization of Compact Stellarators as Power Plants -- Motivations

## Benefits:

- Such a study will advance physics and technology of compact stellarator concept and addresses concept attractiveness issues that are best addressed in the context of power plant studies, e.g.,
  - ✓  $\alpha$  particle loss
  - ✓ Divertor (location, particle and energy distribution and management)
  - ✓ Particular coil configurations.
- NCSX and QSX plasma/coil configurations are optimized for most flexibility for scientific investigations at PoP scale. Optimum plasma/coil configuration for a power plant (or even a PE experiment) will be different. Identification of such optimum configuration will help define key R&D for compact stellarator research program.

# ARIES-Compact Stellarator Program is a ~~Three~~ Four-year Study

## FY03/FY04: Development of Plasma/coil Configuration Optimization Tool

1. Develop physics requirements and modules (power balance, stability,  $\alpha$  confinement, divertor, *etc.*)
2. Develop engineering requirements and constraints.
3. Explore attractive coil topologies.

## FY04/FY05: Exploration of Configuration Design Space

1. Physics:  $\beta$ , aspect ratio, number of periods, rotational transform, shear, *etc.*
2. Engineering: configurationally optimization, management of space between plasma and coils.
3. Choose one configuration for detailed design.

## FY06: Detailed system design and optimization

# Status of ARIES-CS Study

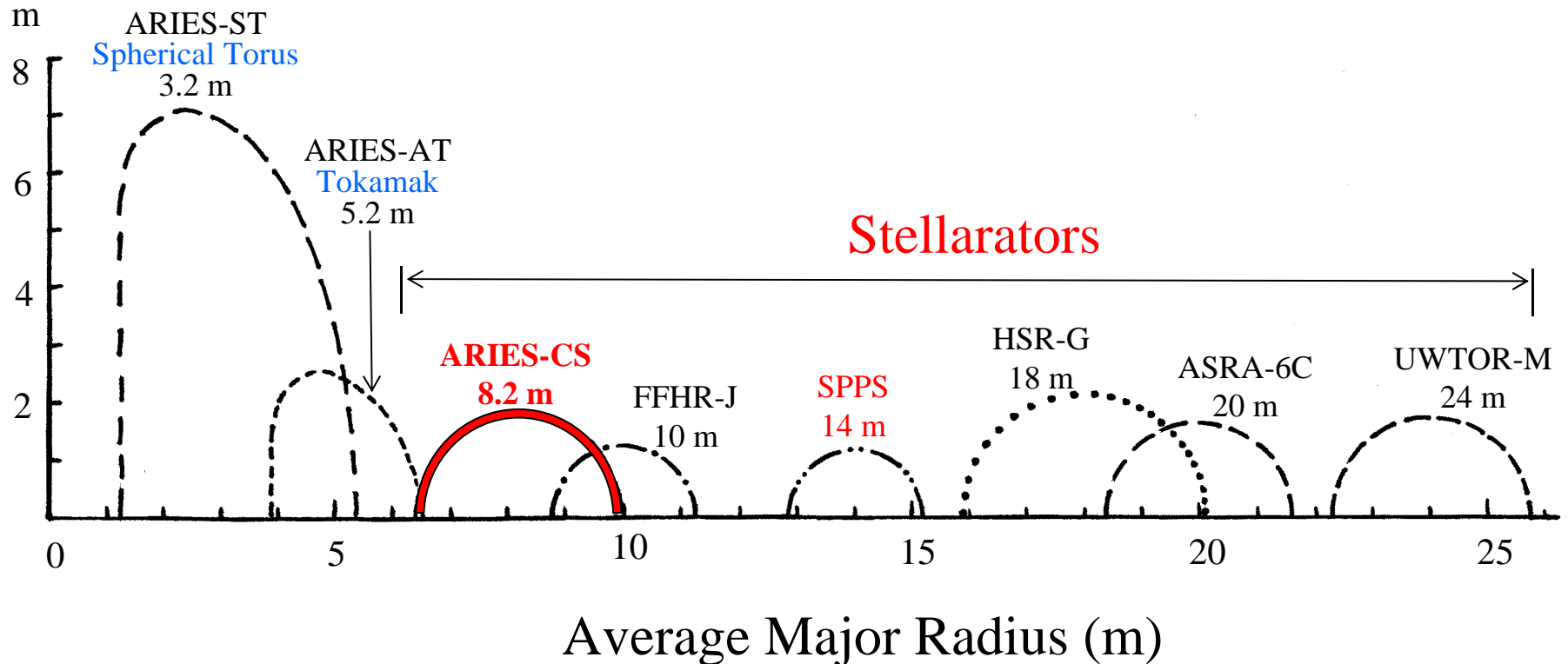
## Program Schedule:

- ARIES Compact Stellarator Study was proposed as a three-year study (Starting in FY03 and completing by FY05).
- Because only half of ARIES effort was devoted to ARIES-CS in FY03 the first phase is extended into FY04.
- Because of reduction in funding in FY04, the second phase will be completed in FY 05 and the study will probably stretch into FY 06.
- Budget Reductions has also led to reduced scope.

## Initial Results:

- We have developed two candidate configuration for self-consistent evaluation. Detailed modeling is on-going (*e.g.*,  $\alpha$ -particle and divertor, MHD  $\beta$  limit)
- Our initial engineering assessment has highlighted maintenance as a key driver for coil/blanket choice and the optimum plasma configuration.

# Comparison of Power Plant Sizes



# An Optimum ARIES-Compact Stellarator Program Plan is a ~\$2M/year effort

## Possible Scenarios for ARIES Research:

- \$1.35M Level – Configuration Exploration
  - ✓ Limited examination and assessment of concepts. No integrated assessment.
- \$1.65M Level – Entry Level for a Power Plant Study
  - ✓ Limited examination of configuration space. Designs will not be fully integrated or self-consistent. Lack of thoroughness will degrade the credibility of the research substantially.
- \$2.0M Level – Comprehensive, integrated, and self-consistent study
  - ✓ Minimum level to support a single, self-consistent design study with thorough examination of configuration space. Results will be credible and will have lasting impact on R&D.
- \$2.3M Level – Comprehensive, integrated, and self consistent study and an additional small scale, preparatory study
  - ✓ Such as H production and how fusion can provide transportation fuel (a contributor to all sectors of energy market).